Physiological and behavioural responses of modification psychomotor task in the virtual reality on cycling

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Abstract

Road cycling requires cyclists to deal naturally with uncertain environments due to different terrain and responses from competitors. Hence, virtual reality is an alternative tool to provide a safe and competitive environment especially for training and performance during competition. This study intends to evaluate the effects of task difficulty levels in the developed virtual reality on alpha/beta ratio, power output, heart rate, and cadence. The eight cyclists were recruited from National Sport School. The environment of virtual reality is modified from the available virtual reality smart trainer TACX system. The one-way multivariate of variance (MANOVA) identified the effect of 5 different levels of the psychomotor task (independent variables) in the virtual reality on multiple variables of physiological responses. The results from MANOVA revealed a statistically significant multivariate main effect ($p < 0.05$) for the 5 levels of task difficulty in road cycling when considered jointly on the variables of alpha/beta ratio, power output, heart rate, and cadence; Wilk's $\lambda = 0.28$, $F(16,98) = 3.19$, partial $\eta^2 = 0.27$. Alternative nonparametric test for a smaller number of participants also shows there was a statistically significant difference ($p < 0.05$) between the 5 levels of task difficulty on alpha/beta ratio and cadence. The result of cadence suggested human interaction with the virtual reality specifically during a psychomotor task to road cycling. The significant effects on the joint physiological responses ensure that the evaluation of the experiment from the procedure of developed task difficulty in the virtual reality is practical and applicable. Future studies could consider an involvement of cognitive functions in response to behavioural mechanism.

1. Introduction

The vast research and application for virtual reality settings have been literate by a systematic review that revealed most of the environments are meant for sports such as running, cycling, rowing, and other interactive sport-related skills (Neumann et al. 2017). Currently, virtual reality is extensively utilized in the sports industry as a tool of training to prepare athletes for competition (Balkó et al. 2018; Cooper et al. 2018; Pereira et al. 2018; Tsai et al. 2019). It also has been employed to various populations and conditions in need to simulate an actual environment (Wiederhold et al. 2002; Kittel et al. 2019). Previous review described several studies conducted on the effect of virtual reality procedure towards multiple parameters such as physiology, behavioural and psychological qualitatively and quantitatively (Neumann et al. 2017). It was previously highlighted that sports performance is anticipated with the interaction of athletes and their ecology involving individual perception and action (Craig 2013). These elements are part of an individual's psychomotor (Paul et al. 2012).

The virtual reality system allows the subject to be physically attached to the system as it provides sensors that are integrated with the system (Tsai et al. 2019). In sport, virtual reality application has potentially used in training, especially during autonomous practice of specific skills (Tsai et al. 2019). Several virtual reality systems have been designed to encounter specific skills. For example, in basketball, the virtual reality was designed to evaluate shooting accuracy and successful throw that comprised some key components of realistic modelling (Covaci et al. 2012). For instance, the virtual reality is more effective and accurate in comparison to video clip methods when handball goalkeeper executes

interception in catching the ball (Vignais et al. 2015). The participants were also able to perform faster. Apart from cognitive-motor performance, the virtual reality was also developed to understand the effect on psychological mechanism. The effect of virtual reality revealed anxiety can be induced during virtual soccer goalkeeping (Bideau et al. 2010) with baseline as a reference (Stinson and Bowman 2014). Meanwhile, in shooting sport, an experiment conducted in a four-sided immersive projection room with retro-projected glass screens found a differential between-subject effect of competition on μ (8-12 Hz) oscillatory activity during aiming (Pereira et al. 2018).

The development of virtual reality opens some questions as to what extent this system provides realistic human interaction with the environment. This is important in the application of sports performance, especially in an open-skilled setting. It does involve the motor performance in which there are processes of visualization as well as individual perception. In reality, the athletes are responded to feedback of spatial reasoning and demand quick, delay, and alternately where pacing and timing are critical in certain situations and conditions. In the road cycling event, it is classified as an open-skilled environment where the environments are uncertain. The competitors that act as objects are also dynamic and indefinite. Cyclists could practice indoors as an alternative training for the outdoor environment since outdoor training is restricted to weather and safety. Nevertheless, without a simulated environment, cyclists may have different motivations to execute the specified workload. Therefore, the visualization of an immersive environment would significantly maximize cyclists' efforts eventually contribute to the effectiveness of training (Balkó et al. 2018).

As cycling is an endurance sport that involves mechanical efficiency, thus, work rate and pedaling technique are crucial in determining performance. According to the previous studies, three physiological parameters that were frequently explored; power output, heart rate, and cadence (Stinson and Bowman 2014; Reed et al. 2016; Smits et al. 2016). These physiological functions are usually responding depending on individual development and performance as well as external factors such as environment and competitiveness. In addition, psychophysiological responses provide a new dimension of the virtual reality (Bronner et al. 2016) effect on neural activity during cognitive-motor process. Hence, there is a need to look into how these parameters are affected by psychomotor task-related to road cycling. To evaluate those parameters, the simulation of the real environment was modified. Therefore, this study aims to explore the effect of modification 5 levels of psychomotor tasks in virtual reality on neurophysiological responses known as alpha/beta power with other physiological responses such as power output, heart rate, and cadence. We also discuss behavioural mechanism of virtual reality and potentially to be an alternative tool for training and evaluation.

2. Methods

2.1 Participants

This study recruited eight female trained development cyclists from the National Sports School. Similar study also employed small sample participants in which each of the study utilize six and fourteen

(Mestre et al. 2011; Bronner et al. 2016). For demographic information, the mean (SD) for age, body mass, and years of experience were 16.25 (1.04), 51.54 (3.99), and 3 (1.41), respectively. The research design of this study complies with the exploration and cross-sectional in which the cyclists are selected based on the inclusion and exclusion criteria set. All cyclists had a similar hours of training hours per week (29 h) and were trained from a similar environment. Before the experiment, all equipment and devices were ensured to be in a good condition. The cyclist was given a participant's information sheet, written informed consent, and a health questionnaire. This study was approved by the National Medical Research & Ethics Committee (MREC) with ethical number 18-3016-42591.

In this study, the selection of participants was done using the purposive sampling method. This method of sampling was used to ensure that the participants were homogenously selected, as they shared similar traits and characteristics. As for the sample size, this sampling method is a non-random technique that does not need underlying theories or a certain number of participants (Etikan et al. 2016). The selection of a purposive sample is often accomplished by applying expert knowledge on the population to select a sample of elements that represents a cross-section of the population in a non-random manner. In this case, a small population from Johor was selected to represent the cross-section of trained cyclists.

2.2 Psychomotor Task in the Virtual Reality

The tasks were designed and modified of available virtual reality road track from the TACX smart trainer system (**Fig.1**). The elements of difficulty are based on the previous study that discussed on task complexity as well as evaluation of human performance (Liu and Li 2012). The flow of experimental procedure was undergoing a process of modification prior to finalizing the different levels of task difficulty. The work on task modification employed 3 experts in sports science to give feedback and evaluate the contents. The first expert has a background of cognitive and motor learning. The second is an expert in motor skill, learning, and development. The last expert is a leader in the field in testing, measurement, and evaluation in sports and exercise. Their feedback received were used to develop and modified the procedure of psychomotor task difficulty during cycling in the virtual reality. Detail's content of the environments is described in **Table 1**. Level 1 is classified as easy, and level 5 is categorized as complex. The level of difficulties is determined by 3 elements of the distance; terrain, visual virtual environment, and the virtual presence of competitors. These elements were included and modified with available virtual track of smart trainer TACX system.

2.3 Procedure

The environment of 5 different levels psychomotor task difficulty is illustrated in **Fig. 2**. The virtual reality was completed by screen visualization and supported by CAVE (**Fig. 3**). The screen was ready for the road cycling environment. In order to measure the corresponding function of alpha/beta ratio, power output, heart rate, and cadence, the virtual reality screen displayed 5 different environments that indicate different levels of difficulty. Meanwhile, all the sensors to record cadence and power output were attached to the bicycle and synchronized with TACX Smart Trainer virtual reality system. The heart rate was recorded using a heart rate monitor. The measurement of power output, heart rate, and cadence was done

using a Garmin power meter, Edge 520. Sensor power output (Vector 2), heart rate monitor, and cadence sensor were calibrated with the Edge 520 power meter. The Garmin sensors were also calibrated with the measurement of the TACX smart trainer system. The bicycle used in this study was the standard road bicycle. It was supported by a smart trainer to stand and fix the standard of the bicycle.

The cyclists were instructed to wear a full set of cycling attire. The explanation was briefed before the experiment and ensured that the cyclists understood the experimental procedure. Coaches were also presented to offer guidance. Subject is informed to complete the first task. The instruction given verbally by the researcher is "You are required to complete 2km distance track at your own pace". The explanation included the possible adverse effects of the screen of computer-aided virtual environment (CAVE) such as the cyclists might feel nauseous due to the screen view. However, it may vary by individual (Rebenitsch and Owen 2014). The nature of this CAVE was considered as an active projection screen as the subject could control the system, which might help in reducing the nausea effect (Sharples et al. 2008). The subject would be stopped if they continuously demonstrated signs of nausea, uneasiness, lack of breath, or if the participant requested to stop. Cyclists needed to pedal to get the data to synchronize with the Garmin power meter before experiment task 1 started.

During the experiment, the researchers were assisted by medical personnel and a lab technician to monitor the safety and the possible signs and symptoms of mental and physical changes. The cycling performance of heart rate, cadence, and power output were monitored entirely, and data from cycling performance were recorded during similar timing of EEG recording. The EEG was measured using wearable bioamplifiers with a differential channel. A bioamplifier is an electrophysiological device, a variation of the instrumentation amplifier, used to gather and increase the signal integrity of physiologic electrical activity for output to various sources. It may be an independent unit or integrated into the electrodes. The EEG recording during rest was 2 minutes. Cyclist was required to continue cycling. They were needed to warm-up for 5 minutes. The environment from the screen was changed after 2 minutes for each of the 5 different virtual reality environments and the EEG was recorded continuously. The maximum time taken in this phase was 25 minutes, including the warm-up session. Subject is allowed to cool down for 5 minutes after they finished all tasks.

2.4 EEG Recording

In this study, EEG recording was employed to measure neural activity. The electrode was placed on Fp1 and Fp2 with the ground electrode placed at the earlobe. The EEG signals were filtered between highpass 0.1 Hz and lowpass 50 Hz. An additional 50 Hz notch filter was applied. Electrode impedances were kept below 5 k Ω for the EEG. All signals were sampled at a frequency of 250 Hz with a resolution of 24 bits. EEG data were pre-processed by removing drifts and lowpass filtering (50 Hz). The signals were determined by applying epoch towards specified psychomotor tasks of the experiments. In the next step, the EEG signals were filtered by applying a fast Fourier transform (FFT) filter for the alpha frequency band (8-12 Hz) and beta frequency band (15-28 Hz). Subsequently, the alpha and beta waves were

calculated and averaged over the epochs representing the recordings during the tasks. The alpha/beta ratio was defined as the alpha power value divided by the beta power value.

2.5 Data Analysis

A quantitative analysis was employed to evaluate the effect of virtual reality on alpha/beta ratio and other physiological functions. The data were analyzed using quantitative analysis, described as descriptive and multivariate analysis of variance (MANOVA), which derived from the Statistical Package for Social Science (SPSS software version 20.0). MANOVA extends the capabilities of analysis of variance by assessing multiple dependent variables simultaneously and detecting patterns between multiple dependent variables. The analysis mainly identified the effect of 5 different levels of the psychomotor task (fixed or independent variables) in the virtual reality on multiple variables of physiological responses. The physiological responses were represented as dependent variables, which were alpha/beta ratio, power output, heart rate, and cadence. The MANOVA was employed to examine the effect of 5 different levels of psychomotor task difficulty on various physiological functions (alpha/beta ratio, power output, heart rate, and cadence). Further analysis from post-hoc comparisons with Bonferroni test to get significant task pairwise differences ($p < 0.05$). Due to a smaller number of participants, we conducted nonparametric test by using Kruskal-Wallis test. The results of these physiological functions determined whether the modified psychomotor task difficulty of virtual reality significantly affects the nurture of cognitive and physiological functions of the targeted subject of interest.

3. Results

Results from the multivariate general linear model showed a significant difference ($p < 0.05$) within-subject on alpha/beta ratio and cadence, but not on power output and heart rate ($p > 0.05$). The Box's M assumption revealed that the covariance matrices of power output, heart rate, and cadence were not significantly different ($p > 0.05$) across levels of task difficulty in road cycling. Thus, it suggested that the model met the assumption of multivariate normality. The results from one-way multivariate analysis of variance revealed a significant multivariate main effect ($p < 0.05$) for 5 levels of task difficulty in road cycling when considered jointly on the variables of alpha/beta ratio, power output, heart rate, and cadence; Wilk's $\lambda = 0.28$, $F(16,98) = 3.19$, partial $\eta^2 = 0.27$. The power to detect the effect was 0.96.

3.1 Univariate Analysis

A separate univariate analysis of variance was conducted for each dependent variable (**Table 2**), with each evaluated at an α level of 0.05. There was a significant difference ($p < 0.05$) between 5 levels of tasks on alpha/beta ratio; $F(4,35) = 2.94$, $p = 0.034$, partial $\eta^2 = 0.25$ and cadence; $F(4,35) = 6.89$, $p = 0.000$, partial $\eta^2 = 0.44$. In **Fig. 4**, Task 1 scored the highest alpha/beta ratio with $M = 0.71$, followed by Task 3 ($M = 0.7$), Task 2 ($M = 0.69$), Task 4 ($M = 0.62$) and Task 5 ($M = 0.51$). In **Fig. 7**, Task 1 scored the highest cadence ($M = 111.57$) followed by Task 4 ($M = 103.41$), Task 3 ($M = 102.09$), Task 2 ($M = 96.96$) and Task 5 ($M = 95.38$). Meanwhile, there was no significant difference ($p > 0.05$) between 5 levels of tasks on power output; $F(4,35) = 2.34$, $p = 0.074$, partial $\eta^2 = 0.21$ (**Fig. 5**) and heart rate; $F(4,35) = 0.44$, $p = 0.776$,

partial $\eta^2 = 0.05$ (**Fig. 6**). Significant task pairwise differences ($p < 0.05$) from post-hoc comparisons with Bonferroni Tests were obtained for cadence between Task 1 and both Task 2 and Task 5. The mean numbers were 111.57 for Task 1, 96.96 for Task 2, and 95.38 for Task 5. Nevertheless, for alpha/beta ratio, the similar post-hoc test showed no significance difference ($p > 0.05$) between the tasks.

3.2 Nonparametric analysis

In this study, the argument of sampling number may result on the validity of the results and the whole experiment. As our study comply with less than 10 participants, we further analyse using nonparametric procedure. The alternative for nonparametric test, we employed Kruskal-Wallis test to confirm the significant statistical analysis. The result shows there is statistically significant between 5 levels of tasks on alpha/beta ratio with $p = 0.045$, power output with $p = 0.043$ and cadence with $p = 0.003$. In comparing these significant values (**table 2**), the power output appears to be statistically significant with significant task pairwise differences ($p < 0.05$) between Task 3 and Task 5. Meanwhile, the task pairwise results remain similar with analysis of MANOVA for alpha/beta ratio and cadence.

4. Discussion

Overall, the univariate analysis on task difficulty in the virtual reality showed a significant effect on alpha/beta ratio despite post hoc comparison finding of no significant results on each task. Furthermore, there was no significant effect on power output and heart rate. This explained that virtual reality stimulates the production of sensory output from the cyclists as they display efforts in response to the task demands (Petukhov et al. 2020). **Fig. 4** and **Fig. 5** describe the average gets higher towards Task 3, which indicated that Task 3 might be the most difficult tasks, or the cyclists were adapting to Task 4 and Task 5. In addition, Task 3 might turn to be an element of the adaptability of expertise towards Task 4 and Task 5, as it included competitors as an element of difficulty. It showed that power output and heart rate dropped from Task 3 to Task 5. The fans or crowd were included in the environment of Task 4 and the distance was added longer in Task 5, but these might not be significant to increase the level of difficulty. It may also result in cyclists' preference as competitors could induce arousal and attention in finishing the race. However, arousal was not aligned with physical effort indicated by power output and heart rate. In sports, athletes develop important skills and perceptual motor coordination to adapt to uncertain situations (Kulpa et al. 2013).

The subject in nature of complexity and difficulty is described in a previous study (Liu and Li 2012), in which the study critically pointed out the interaction of qualitative and quantitative measures to describe the level of task complexity. In this study, despite the insignificant effects on alpha/beta ratio, power output, and heart rate, it is interesting to note the pattern between these parameters. Alpha/beta ratio seemed to deteriorate from Task 3 to Task 5. Meanwhile, heart rate increased towards Task 5 while power output decreased from Task 3 to Task 5. This pattern may indicate the increased task difficulty. Measuring physiological functions from EEG and heart rate was previously carried out as an evaluation for the cognitive load (Armougum et al. 2019). Meanwhile, the pattern of power output is not able to

relate with alpha/beta ratio and heart rate. Since this task has been modified, the argument is limited in comparison with previous studies. In fact, our analysis is also limited to comparison between the 5 levels of psychomotor tasks.

In the meantime, the significant results for cadence on 5 different modified psychomotor task difficulties to road cycling revealed the inherent factors that lie within the area of the psychomotor tasks and human interaction with the environment. The results were supported with the previous studies conducted on the effects of virtual reality on certain skills or tasks (Kulpa et al. 2013; Stinson and Bowman 2014; Cooper et al. 2018) despite their different experimental designs. This study defined the 5 different task demands as psychomotor task difficulty that involved the mechanism of the central nervous system (Li 2004) and perception reasoning (Grabner et al. 2006). The interesting findings were the significant univariate main effect on cadence. These findings are encouraging in relation to the effect of virtual reality induced task difficulty on physiological and behavioural response. The significant difference in cadence shows that terrain and competitors affect the cyclists' pedalling. In cycling, pedalling involves autonomous and controlled processing. The autonomous processing occurs due to neuromuscular adaptation to training, eventually developing the pattern of movement (Ludyga et al. 2016). Thus, it reduces the effort in pedalling. On the other hand, controlled processing requires memory to carry out intentions or action plans to react during uncertain sports conditions (Wang et al. 2019). While the designated tasks involved competitors, especially in Task 3, cyclists were required to make some adjustments of action. In the process of interaction between autonomous and controlled, cyclists demanded cognitive abilities to encounter varied terrains and actions from competitors. These situations contributed to the acceleration and deceleration of cadence (Atkinson et al. 2003). In fact, some cyclists changed their position from seating to standing as a response to inertia. Therefore, the significant results of the main effect for cadence demonstrate human interaction with the virtual reality.

This is critical as the researchers highlighted a user's concern on the presence of interaction in virtual reality (Craig 2013; Vignais et al. 2015; Neumann et al. 2017; Cooper et al. 2018; Pereira et al. 2018). This study was similar to the previous studies in terms of using virtual reality as a tool to evaluate brain activity of spectral power (Petukhov et al. 2020). The study also used virtual reality simulation to evaluate human psychophysiological, including EEG during skiing task. To compare between the virtual reality simulation and real environment, it revealed similar patterns of brain activity that eventually described the presence of realism in the virtual reality system in the context of reproduction of the cyclists' cognitive and peripheral motor program. Meanwhile, increasing multisensory input in the virtual reality even with substituting multimodal sensory feedback (visual, tactile, audio) can potentially increase performance and user's perceived sense of presence (Cooper et al. 2018). In addition, adding competitors as another visual sensory cue in the rowing task improved the subject's performance as measured by the heart rate (Murray et al. 2016).

In summary, the results highlighted the effect of 5 different levels of modified psychomotor task difficulty on multivariate parameters physiological functions as well as the univariate parameter of cadence. The significant effects on physiological responses ensure that the evaluation of the experiment from the

procedure in the virtual reality is practical and applicable. The behavioural mechanism explained during pedalling may give potential insight the involvement of cognitive processes, therefore should include in the future study.

Declarations

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest/Competing interests: No conflict interest.

Availability of data and material: Not applicable.

Code availability: Not applicable.

Ethics approval: This study approved by the National Medical Research & Ethics Committee (MREC) with ethical number 18-3016-42591.

Consent to participate: The cyclist was given a participant's information sheet, written informed consent, and a health questionnaire.

Consent for publication: Not applicable.

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Tables

Table 1 Contents of developed task difficulty in cycling					
Elements	Psychomotor Task Difficulty				
	1	2	3	4	5
Distance	2km	2km	2km	2km	2.5km
Level	Easy	Easy-Moderate	Moderate	Moderate-complex	complex
Terrain	Flat	Mountainous	Mountainous	Open road	Mountainous
Environment	City	Nature	Hilly	Windy	Nature
Competitors	No	No	5 competitors	Crowd + 5 competitors	5 Competitors

Table 2 Univariate analysis of variance between task difficulty				
Parameters	F	Sig.	Partial η^2	Kruskall-Wallis test (Sig.)
Alpha/beta ratio	2.94	0.034*	0.25	0.045*
Power output	2.34	0.074	0.21	0.043*
Heart rate	0.44	0.776	0.05	0.773
Cadence	6.89	0.000*	0.44	0.003*

* $p < 0.05$

Figures

Figure 1

5 Different Levels of Psychomotor Task Difficulty in the Virtual Reality

Figure 2

Flow of Experimental Procedure

Figure 3

The virtual reality completed by screen visualization and supported by CAVE

Figure 4

Alpha/beta ratio during 5 levels of psychomotor task difficulty

Figure 5

Power output during 5 levels of psychomotor task difficulty

Figure 6

Heart rate during 5 levels of psychomotor task difficulty

Figure 7

Cadence during 5 levels of psychomotor task difficulty